City of Hamilton
City Hall Forecourt
Vehicular Impact on Concrete Planter Analysis
November 2020
Revised: February 2021

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GENERAL DESCRIPTION

Kalos Engineering Inc. was retained by the City of Hamilton to provide an assessment and analysis of possible impact scenarios on the concrete planters located in the forecourt of the Hamilton City Hall, located at 71 Main Street West in the City of Hamilton. This assignment was under Category 30- Structural Engineering Services - Facilities, Contract No. C12-06-18 and was authorized by Mr. Sam Gargarello, M. Arch., B. Tech., Project Manager and issued Purchase Order 95507.

A typical planter measures out to be approximately 5ft x 5ft and stands 2' 8" high. The wall thickness of the planters is approximately 4" all around the perimeter and is assumed to be the same for the base. The planters are free floating on top of the forecourt surface in order to be rearranged if required.

The impact scenarios considered in this analysis consist of four test vehicles: a sedan, a pick up truck, a flat bed truck, and a transport truck. The planter was analyzed for each vehicle impacting it at velocities of up to 80km/hour in a head on collision.

This report is limited to the feasibility analysis of a single planter resisting impacts from several vehicle types and does not include the arrangement of the planters within the forecourt or multiple planters working in tandem to resist a vehicular impact.

METHODOLOGY

A typical planter was analyzed under the design loading requirements outlined in the BSI Standards Publication "Impact testing specifications for vehicle security barrier systems". The test scenarios which have been analyzed include several vehicle types of varying weights impacting a single planter at speeds ranging from 16km/h to 80km/h. The four test vehicles analyzed include a typical sedan weighing 1,500 kg, a 2,500 kg pickup truck, and a 3,500 kg flat bed truck. A 32,000 kg 4-axle transport truck was initially considered in our primary analysis but given the low probability of such an impact (based on local traffic), The British standard provided us with the weight and amount of kinetic energy that each vehicle would possess at the varying speeds. Seeing as the planters are free floating, the only force resisting their movement is the frictional force produced between the ground and the planter. Assuming the planters remain rigid, meaning they do not fall apart on impact, we apply the concept of conservation of energy to determine how far a planter would slide when exposed to the various impact scenarios. In this case, the driving force is the kinetic energy produced by the vehicle, while the resisting force is friction between the planter and the ground. The amount of work required to bring the vehicle to a complete stop must be equal to the amount of kinetic energy produced by the vehicle. The work produced by the planter is a function of frictional force multiplied by its sliding distance. Seeing as we know the kinetic energy of the vehicle, and the frictional force produced by the planter, we are able to determine the theoretical distance that a rigid planter would move before bringing the vehicle to complete stop.

Seeing as the equation for kinetic energy = $\frac{1}{2} mv^2$, the velocity of the vehicle exponentially effects the magnitude of kinetic energy produced. This directly correlates to the distance the planter will be pushed upon impact, meaning that at higher impact speeds, the planter is required to slide a significantly larger distance in order to bring the vehicle to a full stop.

The impacting force on the planter applies the same concept of conservation of energy. In this case kinetic energy of the vehicle is equal to the crumple distance of the vehicle multiplied by the resultant force produced upon impact. This allows us to determine the applied force on the planter's face which when divided by its surface area yields a uniformly distributed load. Given that the planters reinforcing is unknown and likely only for general crack resistance, it is assumed to provide no additional support. Therefore the moment resistance of unreinforced concrete is what resists any applied force.

CALCULATIONS

The British Standard provides impact energies for several test vehicle sizes at various speeds. The vehicle sizes range from an average sedan to a Flat bed truck and speeds vary from 16km/h to 80km/h. The wall thickness of the planter was assumed to be constant and the remaining volume was assumed to be filled entirely by soil resulting in an estimated weight of 35kN (7800lbs). The planter was assumed to bear on a gritty concrete surface for which a reasonable coefficient of friction of 0.8 was assumed.

Base on the above noted coefficient of friction, the BSI design criteria for several vehicles, as well as the properties of the existing planter, we were able compile the distance that the planter would need to slide in order to bring the test vehicles to a complete stop at speeds of 16, 48, 64, and 80 km/h. **Table 1** below shows the required stopping distance of the existing planters as they currently stand with no factor of safety applied.

	Existing Planter		
	Sedan (1,500 Kg)	**Pickup** (2.500 Kg)	**Flatbed Truck** (3,500 Kg)
16 Km/hr Speed at Impact	1m (3ft) push distance until full vehicle stop	1m (3ft) push distance until full vehicle stop	1m (4ft) push distance until full vehicle stop
48 Km/hr Speed at Impact	5m (16ft) push distance until full vehicle stop	8m (26ft) push distance until full vehicle stop	11m (36ft) push distance until full vehicle stop
64 Km/hr Speed at Impact	8m (28ft) push distance until full vehicle stop	14m (46ft) push distance until full vehicle stop	20m (65ft) push distance until full vehicle stop
80 Km/hr Speed at Impact	13m (43ft) push distance until full vehicle stop	22m (72ft) push distance until full vehicle stop	31m (101ft) push distance until full vehicle stop

Table 1: The distance an existing planter would need to move in order to stop a several vehicles at a range of speeds.

Once the speed of the vehicles is increased, the distance the planter would move increases considerably. Seeing as kinetic energy is exponentially related to velocity, at a speed of 80Km/hr the sedan would push the planter approximately 13m (43 ft). The stopping distance required by the remaining vehicles is deemed highly infeasible. At this speed the required stopping distance would be approximately 22m (72ft) for the pick up truck, and 31m (100ft) for the flat bed truck.

In addition, for the lightest vehicle moving at a very slow speed (a sedan moving at 16km/hr) with an assumed crumple zone length of 12” the planter would be subjected to a force of 50kN (11,000lbs). This results in an applied force of approximately 4.7 times greater than that which the planter can resist. Therefore, it is highly unlikely the planter would remain intact following an impact and at high speeds may provide little to no support.

Seeing as the results of the primary analysis concluded that the existing planters are not capable of adequately stopping a vehicle without the addition of a factor of safety, the safety factor was omitted. Had the results been reasonable, a safety factor of 2.0 would have been applied in order to ensure protection against unforeseen variables.

In addition to providing an analysis on the feasibility of using the existing planters as crash attenuators, we were also asked to provide a comparison of a couple of options.

The first option includes a potential modification to the existing planters which involves filling 50% of the planters with concrete and the remaining 50% with soil. This would create an increase in weight which directly correlates to an increase in stopping distance of approximately 12.5%. It should be noted that this analysis involves a vehicle hitting the planter perfectly centered and the planter remaining directly in front of the vehicle for the entirety of the stopping distance. In reality, it is possible that the vehicle hits the planter at an irregular angle and pushes it out of the way or environmental factors such as snow, ice, and rain reduce the frictional coefficient between the ground and the planter. all of which could increase the stopping distance required. To adequately account for several factors which may increase the stopping distance, we have applied a factor of safety of 2.0 to the results of this option.

The second option involves introducing an engineered bollard system by others, which would be designed with the intent to bring a vehicle to a complete stop upon impact. The system that was brought forward to us by the city of Hamilton is the PAS 68 25/40 system. This system is designed to meet the BSI impact design criteria which our analysis is based on. The system is designed to withstand an impact from a 2500kg vehicle at speeds of up to 64km/h.

By considering the impact energy that the PAS 68 25/40 system is designed to withstand (which is a function of mass and velocity), we were able to compare similar impact scenarios that the system would cover. This is based on the BSI standards publication which outlines the impact energy for a 2500kg vehicle travelling at 64km/h which is equivalent to 395 kJ.

The stopping distance required by option 1 can be seen below in **table 2**. The highlighted cells of the table indicate scenarios which the PAS 68 25/40 system would be able to withstand based on equal or lesser impact energies of which the system is designed for.

	Option 1: 50% full with concrete		
	Sedan (1,500 Kg)	**Pickup** (2.500 Kg)	**Flatbed Truck** (3,500 Kg)
16 Km/hr Speed at Impact	1m (3ft) push distance until full vehicle stop	2m (5ft) push distance until full vehicle stop	2m (7ft) push distance until full vehicle stop
48 Km/hr Speed at Impact	8m (27ft) push distance until full vehicle stop	14m (46ft) push distance until full vehicle stop	19m (64ft) push distance until full vehicle stop
64 Km/hr Speed at Impact	15m (49ft) push distance until full vehicle stop	25m (81ft) push distance until full vehicle stop	35m (113ft) push distance until full vehicle stop
80 Km/hr Speed at Impact	23m (76ft) push distance until full vehicle stop	39m (127ft) push distance until full vehicle stop	54m (177ft) push distance until full vehicle stop

Table 2: The distance that a planter filled half with concrete and half with soil would need to move in order to stop several vehicle types at a range of speeds. The Highlighted cells indicate scenarios which the PAS 68 25/40 Bollard system should be capable of stopping based on equal or lesser impact energies.

RECOMMENDATIONS

The planters as they currently stand would act very poorly as crash attenuators. For a sedan moving at 80km/hr (which is the most likely impact scenario) a stopping distance of approximately 43 ft is extremely unsafe. Civilians would be required to be at safe distance away from these barriers which would be difficult to ensure and would highly decrease the available area in the forecourt. In addition, the further the sliding distance, the more likely it becomes for the planter to fall apart and produce debris or be pushed out of the way of a vehicle before bringing it to a complete stop.

The Potential solutions that were considered are as follows:

- **Filling a planter halfway with concrete:**
  This would increase the weight of the planter therefore increasing the friction produced between the planter and the ground therefore decreasing the stopping distance of the planter. This method would result in a 12.5% increase in weight which corresponds to a 12.5% decrease in stopping distance.

  It is evident in **table 2** that this system would still require large stopping distances in order to completely stop a vehicle. In addition, there are a large number of variables which may affect the required stopping distance; as a result we have applied a factor of safety of 2.0 to the results to achieve a more reliable stopping distance. Moreover, seeing as concrete is an inherently brittle material, it is inevitable that a portion of planter would break off in an impact scenario and this debris may travel well outside of the intended stopping distance.

Due to the large stopping distance required as well as high potential for debris to be produced as a result of impact, it is our opinion that this system would not be an adequate solution to safely protect against a vehicular collision.

The potential cost implications of this option would be approximately $1000 per planter. This would include cost of labor ($560), cost of materials ($100), Concrete delivery and misc. materials ($440). Although the cost implications of such a modification may be appealing compared to a proprietary system, it is evident that this system cannot be heavily relied upon to stop vehicles.

Purchase an engineered bollard system:
This solution would ensure the forecourt is adequately protected from any possible vehicle collisions. The PAS 68 25/40 system would be an adequate system although it should be noted that the Ontario building code requires foundations of structures to bear at a minimum 1200mm (4ft) below grade. This would ensure the footing has adequate protection from frost heave and would considerably extent the life span of the investment.

According to the results of our analysis, it is our opinion that an engineered bollard system, such as PAS 68 25/40 is the most reliable method of protection to safely and effectively withstand the impact of a moving vehicle.

We trust this to be acceptable to you. Please to not hesitate to contact the undersigned if you have any questions.

Respectfully submitted,

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